FLOW DISTRIBUTION IN STRAIGHT AND MEANDERING COMPOUND CHANNELS

A PROJECT SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Civil Engineering

By

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ROURKELA

Department of Civil Engineering

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CERTIFICATE

This is to certify that the project entitled, "**Flow distribution in meandering compound channels**" submitted by **Biranchi N.Tripathy and Sangireddy Harish** in partial fulfillment of the requirements for the award of **Bachelor of Technology Degree in Civil Engineering** at the **National Institute of Technology, Rourkela (Deemed University)** is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university / institute for the award of any Degree or Diploma.

Date:

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Date: May 10, 2007

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CONTENTS

ABSTRACT

Magnitude of flood prediction is the fundamental for flood warning, determining the development for the present flood-risk areas and the long-term management of rivers. Discharge estimation methods currently employed in river modeling software are based on historic hand calculation formulae such as Chezy's, Darcy-Weisbatch or Manning's equation. More recent work has provided significant improvements in understanding and calculation of channel discharge. This ranges from the gaining knowledge to interpretation of the complex flow mechanisms to the advent of computing tools that enable more sophisticated solution techniques.

When the flows in natural or man made channel sections exceed the main channel depth, the adjoining floodplains become inundated and carry part of the river discharge. Due to different hydraulic conditions prevailing in the river and floodplain, the mean velocity in the main channel and in the floodplain are different. Just above the bank-full stage, the velocity in main channel is much higher than the floodplain. Therefore the flow in the main channel exerts a pulling or accelerating force on the flow over floodplains, which naturally generates a dragging or retarding force on the flow through the main channel. This leads to the transfer of momentum between the main channel water and that of the floodplain. The interaction effect is very strong at just above bank full stage and decreases with increase in depth of flow over floodplain. The relative "pull" and "drag" of the flow between faster and slower moving sections of a compound section complicates the momentum transfer between them. Failure to understand this process leads to either overestimate or underestimate the discharge leading to the faulty design of channel section. This causes frequent flooding at its lower reaches.

Due to transfer of momentum between the subsections of the meandering compound channel, the shear distribution is largely affected. For such compound channels, the apparent shear force at the assumed interface plane gives an insight into the magnitude of flow interaction. The results of some experiments concerning the velocity distribution and the flow distribution in a smooth and rough compound meandering channel of rectangular cross section are presented. The influence of the geometry on velocity and flow distribution and different functional relationships are obtained.

Dimensionless parameters are used to form equations representing the velocity distribution and flow distribution between main channel and flood plain subsections. Once these equations get formed one can judge the exact flow in main channel and flood channel sections which could possibly guide in flood prediction.

The experiments concerning the flow in simple meander channels and meander channel - floodplain geometry have been conducted at the Fluid Mechanics and Water Resources Engineering Laboratory of the Department Civil Engineering, National Institute of Technology, Rourkela, India. Channels of different shapes and sizes have been fabricated in the laboratory with different equipments installed in them. Water is allowed to flow through these channels and the flow is maintained smooth. The Acoustics Doppler Velocitimeter (ADV**)** installed in the lab is worth mentioning. Taking the aid of a laptop terminal, this equipment helps in determining the three-dimensional velocities (Vx, Vy, Vz) at any point in the water channel.

All the velocity readings obtained are recorded and finally velocity contours (i.e. isovels) are plotted with a software 3D-Field. Depending on the flow pattern and shape of the channel, contours are obtained. All the contours are converted to bitmap image and finally inputted in MATLAB software. Now with this software discharge through a channel cross-section is generated which when compared to the actual flow discharge gives a very less percentage of error. Finally equations related to the flow distribution are formed based on the given datas. These formed equations are validated with datas collected from IIT Kharagpur **(**Bhattacharya, A. K. (1995) and those from Knight and Demetriou**(** Knight, D.W., and Demetriou, J.D., (1983) which satisfies them as well.

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Chapter 1

INTRODUCTION

INTRODUCTION

Investigators have studied meanders and straight compound channels flows for a fairly long time. The name meander, which probably originated from the river Meanders in Turkey is so frequent in river that it has attracted the interest of investigators from many disciplines. Thomson (1876), was probably the first to point out the existence of spiral motion in curved open channel. Since then, a lot of laboratory and theoretical studies have been reported, more so, in the last decade or two. It may be worth while to know the developments in the field of constant curvature bends, simple meander channel flows and straight compound channels before knowing about the meander channel-floodplain geometry as limited studies concerning the meander plan form of the compound sections are available till date.

Information regarding the nature of flow distribution in a flowing simple and compound channel is needed to solve a variety of river hydraulics and engineering problems such as to give a basic understanding of resistance relationship, to understand the mechanism of sediment transport, to design stable channels, revetments.

The flow distribution, velocity distribution and flow resistance in compound cross section channels have been investigated by many authors.

Most of the flow distribution formulae assume that the roughness coefficient and the other geometrical parameters of natural river channel do not change when the flow starts overtopping the main channel.

For meandering channels the flood plain geometry, the wide variation in local shear stress distribution from point to point in the wetted perimeter varies.

Therefore there is need for taking into account these parameters and developing one rock solid model which would predict the discharge accurately during flood forecasting.

Chapter 2

REVIEW OF LITERATURE

2.1 SIMPLE MEANDER CHANNELS

The Meandering channel flow is considerably more complex than constant curvature bend flow. The flow geometry in meander channel due to continuous stream wise variation of radius of curvature is in the state of either development or decay or both. The following important studies are reported concerning the flow in meandering channels.

Hook (1974) measured the bed elevation contours in a meandering laboratory flume with movable sand bed for various discharges. For each discharge he measured the bed shear stress, distribution of sediment in transport and the secondary flow and found that with increasing discharge, the secondary current increased in strength.

Chang (1984 a) analyzed the meander curvature and other geometric features of the channel using energy approach. It established the maximum curvature for which the river did the last work in turning, using the relations for flow continuity, sediment load, resistance to flow, bank stability and transverse circulation in channel bends. The analysis demonstrated how uniform utilization of energy and continuity of sediment load was maintained through meanders.

2.2 COMPOUND CHANNELS IN STRAIGHT REACHES

While simple channel sections have been studied extensively, compound channels consisting of a deep main channel and one or more floodplains have received relatively little attention. Analysis of these channels is more complicated due to flow interaction taking place between the deep main channel and shallow floodplains. Laboratory channels provide the most effective alternative to investigate the flow processes in compound channels as it is difficult to obtain field data during over bank flow situations in natural channels. Therefore, most of the works reported are experimental in nature.

Sellin (1964) confirmed the presence of the "kinematics effect" reported by Zheleznyakov(1965) after series of laboratory studies and presented photographic evidence of the presence of a series of vortices at the interface of main channel and flood plain. He studied the channel velocities and discharge under both interacting and isolated conditions by introducing a thin impermeable film at the junction. Under isolated condition, velocity in the main channel was observed to be more and under interacting condition the velocity in floodplain was less.

Rajaratnam and Ahmadi (1979) studied the flow interaction between straight main channel and symmetrical floodplain with smooth boundaries. The results demonstrated the transport of longitudinal momentum from main channel to flood plain. Due to flow interaction, the bed shear in floodplain near the junction with main channel increased considerably and that in the main channel decreased. The effect of interaction reduced as the flow depth in the floodplain increased.

Knight and Demetriou (1983) conducted experiments in straight symmetrical compound channels to understand the discharge characteristics, boundary shear stress and boundary shear force distributions in the section. They presented equations for calculating the percentage of shear force carried by floodplain and also the proportions of total flow in various sub-areas of compound section in terms of two dimensionless channel parameters. For vertical interface between main channel and floodplain the apparent shear force was found to be more for low depths of flow and for high floodplain widths. On account of interaction of flow between floodplain and main channel it was found that the division of flow between the subsections of the compound channel did not follow a simple linear proportion to their respective areas.

Knight and Hamed (1984) extended the work of Knight and Demetriou (1983) to rough floodplains. The floodplains were roughened progressively in six steps to study the influence of different roughness between floodplain and main channel to the process of lateral momentum transfer. Using four dimensionless channel parameters, they presented equations for the shear force percentages carried by floodplains and the apparent shear force in vertical, horizontal diagonal and bisector interface plains. The apparent shear force results and discharge data provided the weakness of these four commonly adopted design methods used to predict the discharge capacity of the compound channel.

2.3 MEANDERING COMPOUND CHANNELS

There are limited reports concerning the characteristics of flow in meandering compound sections.

A study by United States water ways experimental station (1956) related the channel and floodplain conveyance to geometry and flow depth, concerning, in particular, the significance of the ratios of channel width to floodplain width and meander belt width to floodplain width in the meandering two stage channel.

Toebes and Sooky (1967) were probably the first to investigate under laboratory conditions the hydraulics of meandering rivers with floodplains. They attempted to relate the energy loss of the observed internal flow structure associated with interaction between channel and floodplain flows. The significance of helicoidal channel flow and shear at the horizontal interface between main channel and floodplain flows were investigated. The energy loss per unit length for meandering channel was up to 2.5 times as large as those for a uniform channel of same width and for the same hydraulic radius and discharge. It was also found that energy loss in the compound meandering channel was more than the sum of simple meandering channel and uniform channel carrying the same total discharge and same wetted perimeter. The interaction loss increased with decreasing mean velocities and exhibited a maximum when the depth of flow over the floodplain was less. For the purpose of analysis, a horizontal fluid boundary located at the level of main channel bank full stage was proposed as the best alternative to divide the compound channel into hydraulic homogeneous sections. Hellicoidal currents in meander floodplain geometry were observed to be different and more pronounced than those occurring in a meander channel carrying in bank flow. Reynold's number (R) and Froude number (F) had significant influence on the meandering channel flow.

Ghosh and Kar (1975) reported the evaluation of interaction effect and the distribution of boundary shear stress in meander channel with floodplain. Using the relationship proposed by Toebes and Sooky (1967) they evaluated the interaction effect by a parameter (*W*). The interaction loss increased up to a certain floodplain depth and there after it decreased. They concluded that channel geometry and roughness distribution did not have any influence on the interaction loss.

Ervine, Willetts, Sellin and Lorena (1993) reported the influence of parameters like sinuosity, boundary roughness, main channel aspect ratio, and width of meander belt, flow depth above bank full level and cross sectional shape of main channel affecting the conveyance in the meandering channel. They quantified the effect of each parameter through a non-dimensional discharge coefficient F^* and reported the possible scale effects in modeling such flows.

Patra and Kar (2000) reported the test results concerning the boundary shear stress, shear force, and discharge characteristics of compound meandering river sections composed of a rectangular main channel and one or two floodplains disposed off to its sides. They used five dimensionless channel parameters to form equations representing the total shear force percentage carried by floodplains. A set of smooth and rough sections is studied with an aspect ratio varying from 2 to 5. Apparent shear forces on the assumed vertical, diagonal, and horizontal interface plains are found to be different from zero at low depths of flow and change sign with an increase in depth over the floodplain. A variable-inclined interface is proposed for which apparent shear force is calculated as zero. Equations are presented giving proportion of discharge carried by the main channel and floodplain. The equations agreed well with experimental and river discharge data.

Patra and Kar (2004) reported the test results concerning the velocity distribution of compound meandering river sections composed of a rectangular main channel and one or two floodplains disposed off to its sides. They used dimensionless channel parameters to form equations representing the percentage of flow carried by floodplains and main channel sub sections.

Shiono, Romaih &Knight (2004) carried out discharge measurements for over bank flow in a two-stage meandering channel with various bed slopes, sinuosities, and water depths. The effect of bed slope and sinuosity on discharge was found to be significant. A simple design equation for the conveyance capacity based on dimensional analysis is proposed. This equation may be used to estimate the stage-discharge curve in a meandering channel with over bank flow. Predictions of discharge using existing methods and the proposed method are compared and tested against the new measured discharge data and other available over bank data. The strengths and weaknesses of the various methods are discussed.

Chapter 3

EXPERIMENTAL SET-UP

3.1 EXPERIMENTAL SETUP

The experiments concerning the flow in meander channel, meander channel- floodplain and straight channel-flood plain geometry were conducted at the Fluid Mechanics and Hydraulics Engineering Laboratory of the Civil Engineering Department, National Institute of Technology, Rourkela, India. The compound meandering/straight channel consisting of a meandering/straight main channel with equal flood plains on both sides is fabricated (Figs. 3.1). A photo graphs of the experimental channel with measuring equipments taken from the up stream side end is shown in (photo 3.1).A photo graphs of the same channel with measuring equipments taken from the down stream side end is shown in photo (3.2). The channel surfaces formed out of Perspex sheets represents smooth boundary (Figs. 3.2). The channels are placed inside a rectangular tilting flume made out of metal frame and glass walls. The tilting flume has the overall dimension of 12 m long and 0.60 m wide. To facilitate fabrication, the whole channel length has been made in blocks of 1.20 m length. Meandering compound channel configurations were molded out of 50-mm-thick perspex, which were cut to the dimensions of the appropriate configuration. These were then glued and sealed to the base of the flume. The model thus fabricated has a wavelength L = 40cm, double amplitude 2A'= 32.3cm,12cm×12 cm main channel and flood plain width B = 45.7cm.The centerline of the meandering channel is taken as sinusoidal having sinuosity = 1.44.

In another set up of a straight compound channel, all surfaces of the channel are made up of Perspex sheets (same material as the meandering compound channel) to represents also the smooth boundary (Figs. 3.3). The model for straight symmetrical compound channel thus fabricated has 12cm×12cm main channel and the flood plain width of 32 cm. The iron framed flume has the overall dimension of 12 m long and 0.50 m wide and 0.5 m depth (photo 3.3). To facilitate fabrication, the whole channel length has been made in blocks of 1.20 m length.

All measurements were carried out under uniform flow conditions by setting the water surface slope, using the downstream tailgate, parallel to the valley slope for straight channel and parallel to the valley bed slope at each meander wavelength. Points 2 m from both the inlet and outlet of the flume were eliminated from this slope estimation. The flume is adequately supported on suitable masonry at its bottom. The geometrical parameters of the experimental channels are given in Table-1.

A schematic diagram of the experimental setup for the channels is shown in Fig. 3.3. A re circulating water supply was present. A pumps pumped water from underground sump to an overhead tank. Water is supplied to the experimental channel from that overhead tank**.** A glass tube indicator with a scale arrangement in the overhead tank enables to draw water with constant flow head. The stilling tank located at the upstream of the channel has a baffle wall to reduce turbulence of the incoming water. An arrangement for the smooth transition of water from the stilling tank to the experimental channel is made. At the end of the experimental channel, water is allowed to flow over a tailgate and into a sump. From the sump water is pumped back to the overhead tank, thus setting a complete re-circulating system of water supply for the experimental channel. The tailgate helps to establish uniform flow in the channel. When the deviation of the pseudo water surface slope from the bed slope became less than 2%, it was accepted as attaining the quasi-uniform flow condition. It should be noted that the establishment of a flow that has its water surface parallel to the valley slope (where the energy losses are equal to potential energy input) may become a standard whereby the conveyance capacity of a meandering channel configuration can be assessed. The water surface slope measurement was carried out using a pointer gauge, operated manually, and reading to the nearest 0.1 mm at the center of the crossover sections. A hand-operated tailgate weir was constructed at the downstream end of the channel to regulate and maintain the desired depth of flow in the flume. From the stilling tank water is led to the experimental channel through a baffle wall and a transition zone helped to reduce turbulence of the flowing water. Water from the channel is collected in a masonry volumetric tank from where it is allowed to flow back to the underground sump. An adjustable tail gate at the downstream end of the flume helps to achieve uniform flow over the central test region. Point velocities were measured with 16-MHz Micro ADV (Acoustic Doppler Velocity meter) at different location across the channel section are made.

The discharge is measured by the time rise method. The water flowing out of the exit end of the experimental channel is diverted to a rectangular measuring tank of 198.5 cm long and 190 cm wide for meandering compound channel and 169 cm long and 103 cm wide for straight compound channel. The change in the depth of water with time is measured by a glass tube indicator system with a scale of accuracy 0.01cm. A traveling steel bridge spans the width of the composite channel and can be moved along the length of the channel on guide rails provided at the top of the flume. The bridges either supports either of a point gauge or the micro-ADV which can be moved in the transverse as well as in the longitudinal direction. As the ADV is unable to read the upper layer(up to 5cm from free surface) so a micro -pitot tube of (4mm external diameter) with a flow direction finder arrangements are used to measure some point velocity and its direction with in that locations of the flow-grid points.

3.2 SCHEME OF EXPERIMENTS

Both the tests are conducted with smooth meander channel and floodplain surfaces. In the The present work is based on the results of the following 32 experimental runs. For both straight and meandering channel with simple cross section, the d/b ratio varies between 0.21-0.86 in straight channel case and **-**0.21-0.96**,** can be said as to gave a d/b ratio just falls in deep meander category.

Table 3.2 Details of Experimental Runs

Series	Channel Section Type	Maximum Depth of Flow	Maximum Discharge(cm^3/sec)	Number of Runs.
I	Straight	20.32	5200	9
II	Straight with Flood plain	20.65	30800	7
III	Meander	11.42	4656	15
IV	Meander with Flood plain	20.32	30800	11

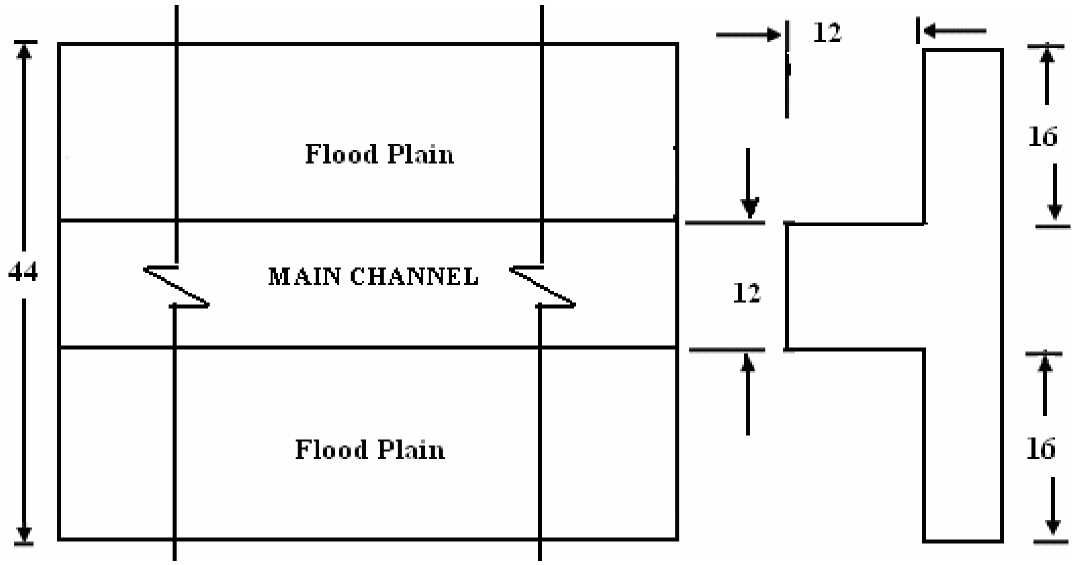


Fig 3.1. Top view of the main channel with adjoining flood plains.

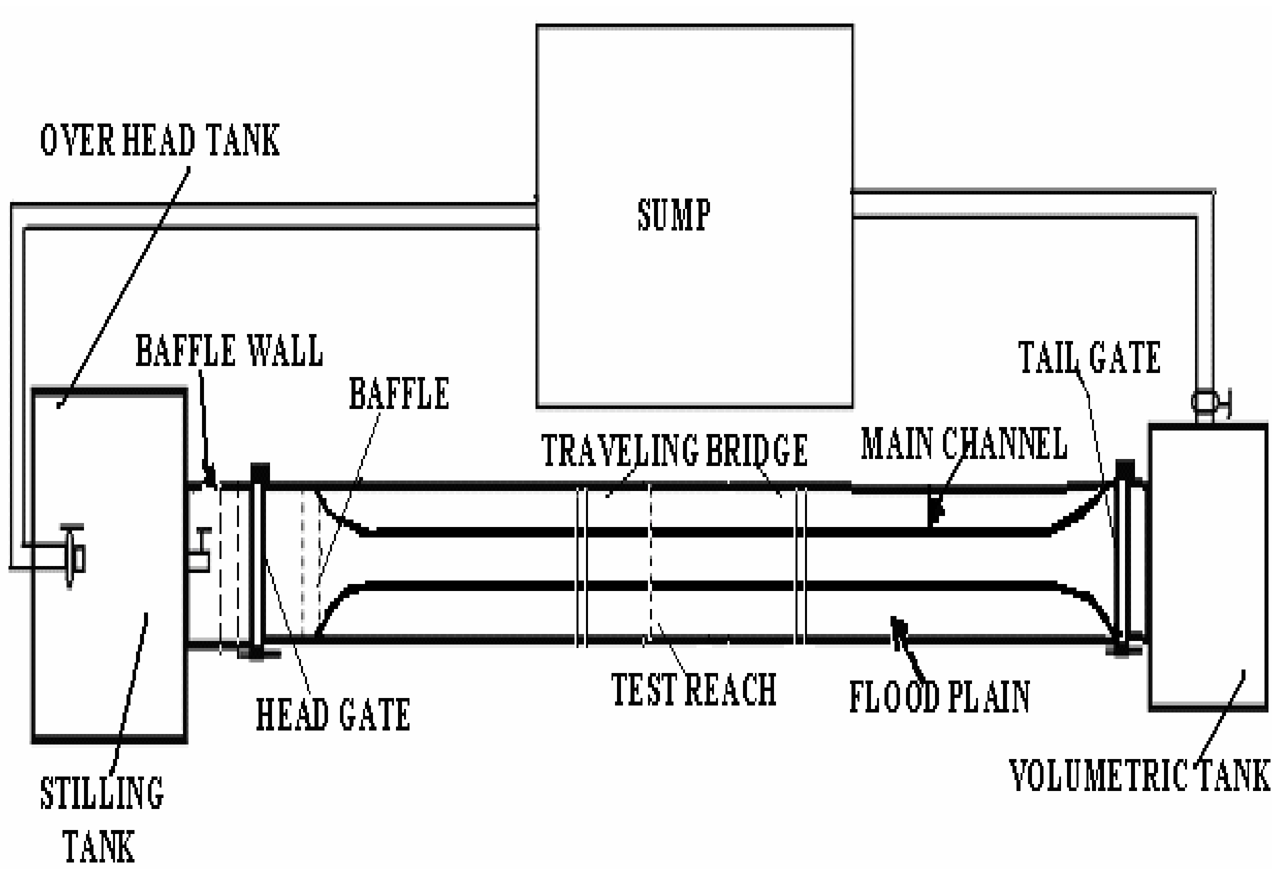


Fig 3.2 Experimental set up with plan form of the straight channel with floodplain

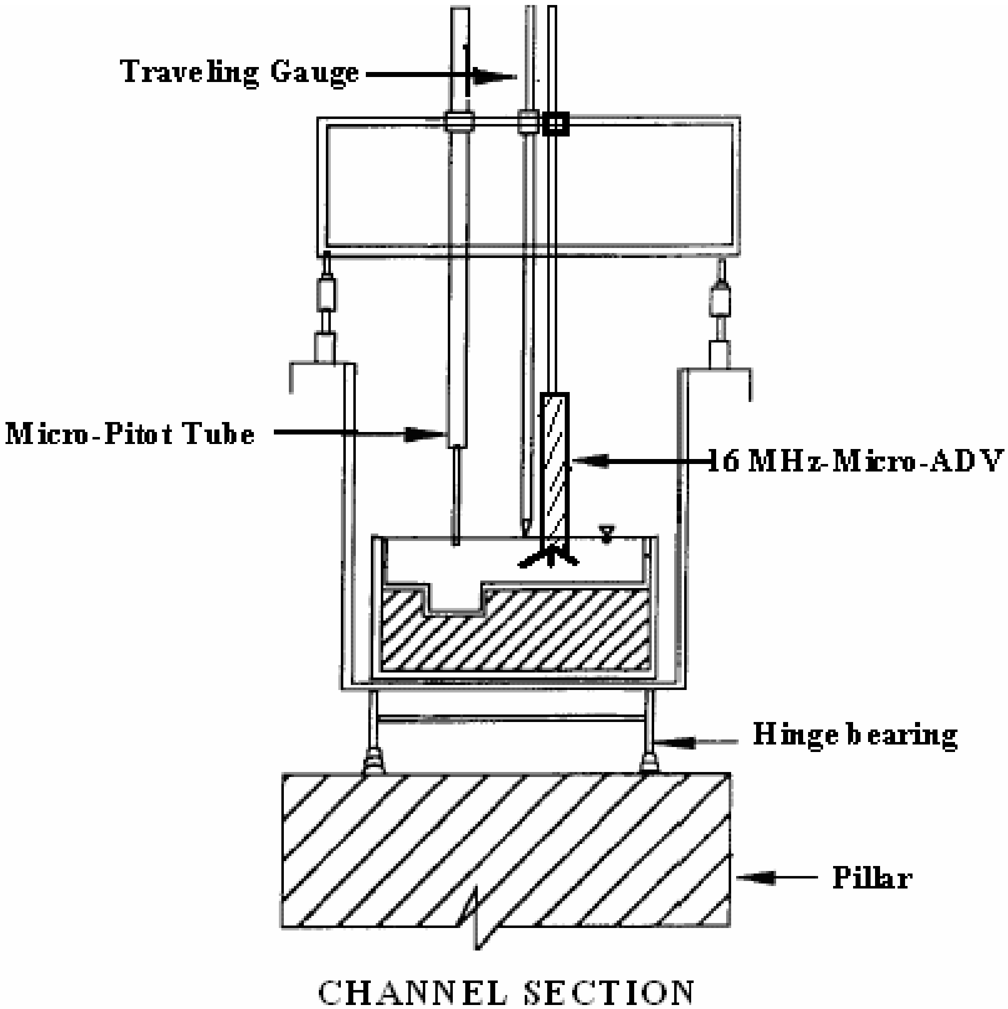


Fig 3.3. Channel section shown along with ADV positioning operation

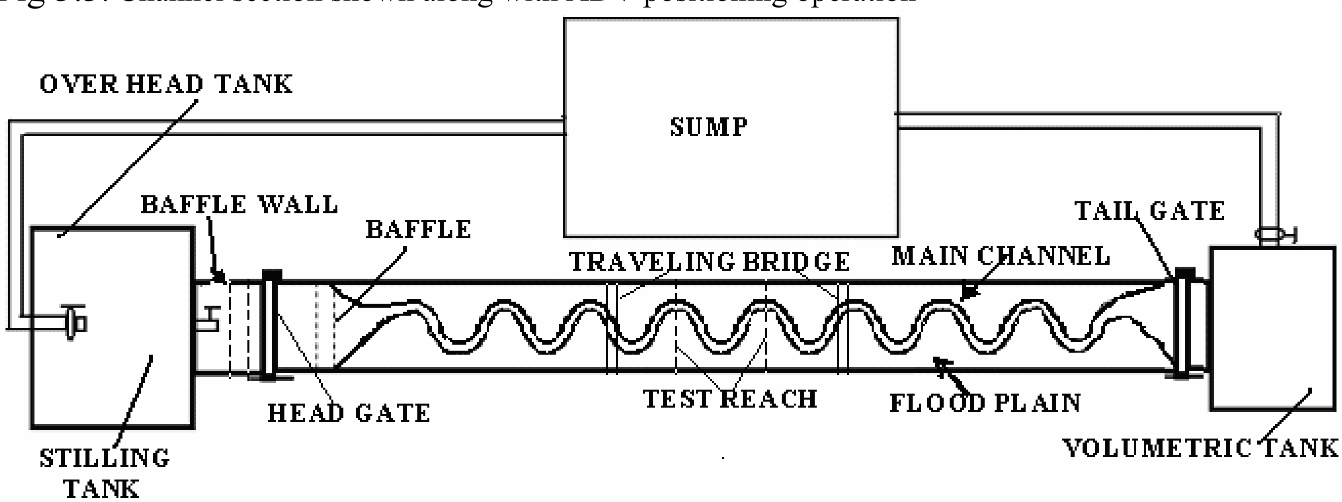


Fig3.4 Experimental set up with plan form of the meandering channel with floodplain

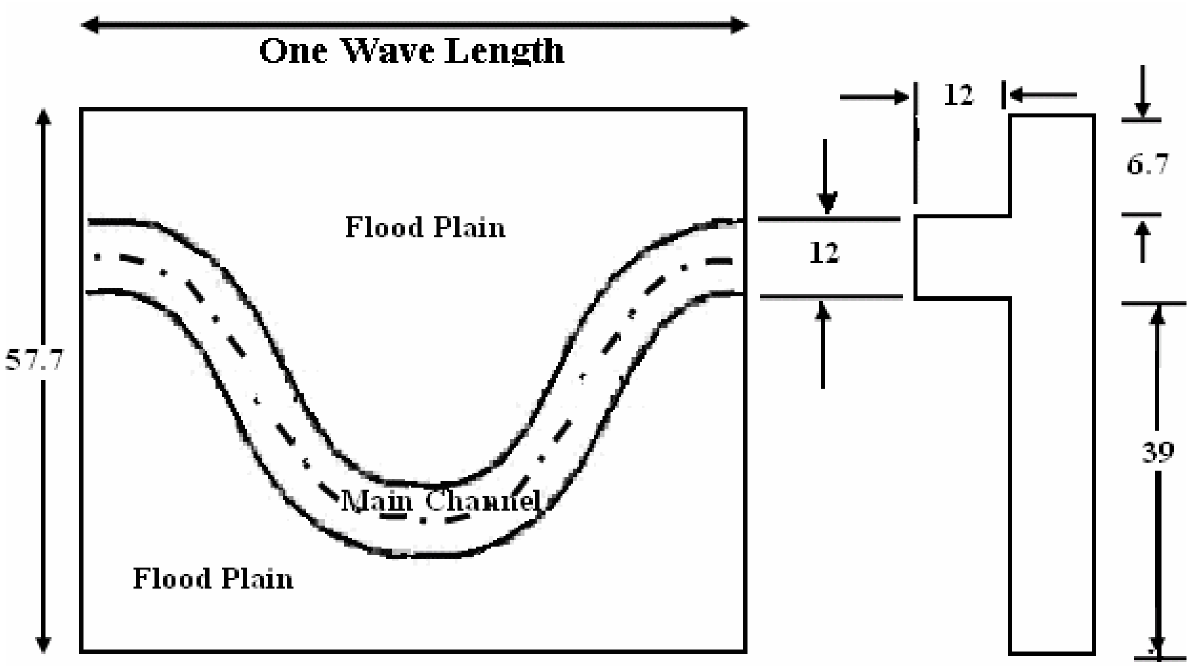


Fig.3.5 One wave length of meandering compound channel

3.3 EXPERIMENTAL PROCEDURE

3.3.1 Determination of Channel Slope

By blocking the tail end, the impounded water in the channel is allowed to remain standstill. The levels of channel bed and water surface are recorded at a distance of one wavelength along its centerline. The mean slope for each type of channel is obtained by dividing the level difference between these two points by the length of meander wave along the centerline. The valley slope for both the straight compound and meandering compound channels are kept same and is equal to 0.0054.

3.3.2 Measurement of Discharge and water surface elevation

A point gauge with a least count of 0.01cm was used to measure the water surface elevation above the bed of main channel or flood plain. As mentioned before, a measuring tank located at the end of test channel receives water flowing through the channels Depending on the flow rate the time of collection of water in the measuring tank varies between 50 to 240 seconds, lower one for higher discharge. The change in the mean water level in the tank for the time interval is recorded. From the knowledge of the volume of water collected in the measuring tank and the corresponding time of collection, the discharge flowing in the experimental channel is obtained.

3.3.3 Measurement of Velocity and its Direction

16-MHz Micro ADV (Acoustic Doppler Velocity meter) from the original Son-Tek, San Diego, Canada, is the most significant breakthrough in 3-axis (3D) Velocity meter technology. The higher acoustical frequency of 16 MHz makes the Micro-ADV the optimal instrument for laboratory study. After setup of the Micro ADV with the software package it is used for taking high-quality three dimensional Velocity data at different points of the flow area are received to the ADV-processor. Computer shows the raw data after compiling the software package of the processor. At every point the instrument is recording a number of velocity data for a minute. With the statistical analysis using the installed software, the mean value of the point velocities (three dimensional) were recorded for each flow depths. The Micro -ADV uses the Doppler shift principle to measure the velocity of small particles, assuming to be moving at velocities similar to the fluid. Velocity is resolved into three orthogonal components(Tangential, radial and vertical), and measured in a volume 5 cm below the sensor head, minimizing interference of the flow field, and allowing measurements to be made close to the bed.

The Micro ADV has the Features like

- Three-axis velocity measurement
- High sampling rates -- up to 50 Hz
- Small sampling volume -- less than 0.1 cm^3
- Small optimal scatterer -- excellent for low flows
- High accuracy: 1% of measured range
- Large velocity range: 1 mm/s to 2.5 m/s
- Excellent low-flow performance
- No recalibration needed
- Comprehensive software

As the ADV is unable to read the upper layer velocity i.e. up to 5cm from free surface so A standard Prandtl type micro-pittot tube in conjunction with a water manometer of accuracy of 0.012 cm is also used for the measurement of point velocity readings at some specified location for the upper 5cm region from free surface across the channel. The results have been discussed in the next chapter.

DETAILS OF STRAIGHT CHANNEL WITH FLOOD PLAIN

Experimen series/ Run No	Nature of Channel surface	Bed slope	Top width *B*(cm)	Main channe Width *b*(cm)	Depth over Main channel *h* (cm)	Depth of lower Main channel (cm)	$\alpha = B/b$	$\beta = (H-h)/H$	Discharge (cm^3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	smooth	0.0054	44	12	14.02	12	3.667	0.143	9006
2	smooth	0.0054	44	12	15.12	12	3.667	0.206	12245
3	smooth	0.0054	44	12	15.34	12	3.667	0.218	13000
4	smooth	0.0054	44	12	16.57	12	3.667	0.276	16700
5	smooth	0.0054	44	12	17.55	12	3.667	0.316	19860
6	smooth	0.0054	44	12	20.65	12	3.667	0.419	30800

DETAILS OF MEANDERING CHANNEL WITH FLOOD PLAIN

Experiment series/ Run No	Nature of Channel surface	Bed slope	Top width *B*(cm)	Main channel Width *b*(cm)	Depth over Main channel *h* (cm)	Depth of lower Main channel (cm)	$\alpha = B/b$	$\beta = (H-h)/H$	Sinuosity S_r	Discharge (cm^3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	smooth	0.0054	57.7	12	13.30	12	4.808	0.0977	1.44	5714. 4
2	smooth	0.0054	57.7	12	14.24	12	4.808	0.1573	1.44	9006.5
3	smooth	0.0054	57.7	12	14.65	12	4.808	0.1809	1.44	10107.6
4	smooth	0.0054	57.7	12	14.80	12	4.808	0.1892	1.44	10493.5
5	smooth	0.0054	57.7	12	15.30	12	4.808	0.2157	1.44	12245.6
6	smooth	0.0054	57.7	12	15.60	12	4.808	0.2327	1.44	13005.2
7	smooth	0.0054	57.7	12	16.36	12	4.808	0.2665	1.44	15289.8
8	smooth	0.0054	57.7	12	16.80	12	4.808	0.285	1.44	16762.2
9	smooth	0.0054	57.7	12	17.57	12	4.808	0.317	1.44	19866.7
10	smooth	0.0054	57.7	12	19.04	12	4.808	0.3697	1.44	25661.8
11	smooth	0.0054	57.7	12	20.32	12	4.808	0.409	1.44	30800.1

Chapter 4

OBSERVATIONS

4.1 Calculation of the three dimensional velocities

As stated above, the three dimensional velocities at different heights of water level are calculated and are pre recorded in the tables below:

4.1.1 Compound meandering channels

At flow depth H= 20.5 cm

x	y	Vx	Vy
3.5	19.0	63.0	-2.4
3.5	15.0	62.8	-5.7
3.5	12.5	32.3	-5.3
6.7	19.0	64.8	-6.7
6.7	15.0	59.1	-6.1
6.7	14.0	41.5	-7.4
6.7	12.5	28.1	-6.5
8.2	19.0	68.4	-3.6
8.2	15.0	57.6	-1.9
8.2	11.7	24.6	-0.8
8.2	9.4	25.0	-1.9
8.2	7.0	41.0	-1.6
12.7	19.0	62.4	-1.7
12.7	15.0	53.7	0.1
12.7	11.4	35.5	0.4
12.7	5.4	32.1	-7.0
12.7	3.0	28.6	-9.9
12.7	0.5	20.0	-11.3
15.7	19.0	64.8	-1.9
15.7	14.0	52.0	0.4
15.7	11.4	38.4	-0.2
15.7	8.4	34.5	-0.3
15.7	3.0	29.0	-9.5
17.2	19.0	65.0	-0.8
17.2	13.0	46.2	1.6
17.2	11.7	36.5	2.8
17.2	7.0	35.3	-2.5
18.2	19.0	66.0	-3.0
18.2	15.0	53.4	-2.6
18.2	11.7	41.8	0.6
18.2	9.4	39.2	0.6

18.2	7.0	1.8	25.1
24.7	19.0	70.8	-9.6
24.7	15.0	52.6	-4.2
24.7	14.0	59.5	-5.1
24.7	12.5	42.4	-4.1
30.7	19.0	71.0	-4.7

At flow depth H=19.6 cm

x	y	Vx	Vy	Vz
5.5	14.6	41.0	-11.1	1.9
5.5	13.6	48.6	-3.6	0.2
5.5	11.0	43.4	-1.2	-0.3
6.7	14.6	45.4	-0.2	2.7
6.7	13.6	38.4	-0.9	3.5
6.7	9.0	24.6	-1.5	7.4
6.7	7.0	39.8	11.4	4.4
8.2	14.6	44.0	1.2	2.8
8.2	13.6	37.6	0.4	3.2
8.2	7.0	39.2	10.5	4.2
8.2	9.0	27.6	-2.8	6.6
9.7	14.6	37.4	1.2	3.5
9.7	13.7	32.8	1.5	4.1
9.7	11.0	28.6	1.5	6.8
9.7	7.0	28.0	-3.1	6.3
9.7	0.5	20.0	-6.4	1.1
12.7	14.6	44.0	4.2	1.7
12.7	13.7	38.0	4.4	2.1
12.7	11.0	35.8	3.2	3.1
12.7	7.0	33.6	-4.4	5.1
12.7	0.5	23.0	-11.3	0.6
15.7	14.6	33.6	-4.4	-8.6
15.7	13.7	36.2	-2.7	1.1
15.7	11.0	36.6	4.5	-1.6
15.7	7.0	32.8	-4.1	-4.8
15.7	0.5	30.8	-12.3	-1.8
16.2	14.6	43.6	3.5	-1.4
16.2	13.6	40.2	4.2	-3.7
16.2	9.0	36.4	-1.7	-8.3
16.2	7.0	33.6	-4.4	-8.6
18.7	9.0	35.0	-1.6	-11.1
18.7	7.0	32.6	-3.9	-11.6
22.7	13.6	54.8	-1.9	-1.4
22.7	11.0	54.0	-1.3	-1.4
32.7	13.6	51.2	-0.2	-1.5
32.7	11.0	24.8	2.0	-0.1
37.7	14.6	36.0	-7.4	-0.3

37.7	11.0	38.8	1.7	-0.5
37.7	13.6	41.6	-0.1	-1.1
42.7	14.6	30.8	-0.4	1.4
42.7	13.6	30.4	-1.3	0.2
42.7	11.0	29.4	-3.4	-0.5
47.7	14.6	33.4	-8.1	0.6
47.7	13.6	40.8	-1.2	-1.4
47.7	11.0	30.4	-0.8	-0.4
52.7	13.6	51.0	-1.3	0.4
52.7	14.6	50.6	-3.7	0.2
52.7	11.0	46.0	-0.5	-0.8

At flow depth H =16.5 cm

X	Y	Vx	Vy	Vz
17.7	11.5	41.2	4.3	-3.1
17.7	9.0	36.0	0.7	-5.9
17.7	5.5	34.2	-7.3	-4.0
17.7	3.0	36.7	-8.6	-2.2
17.7	0.5	34.2	-8.2	-1.7
17.7	0.3	31.2	-6.7	-0.5
15.7	11.5	39.2	3.5	-3.6
15.7	9.0	34.0	1.5	-5.3
15.7	5.5	33.7	-7.2	1.2
15.7	3.0	37.0	-8.8	-2.6
15.7	0.5	33.5	-6.6	-1.5
15.7	0.3	33.5	-6.7	-0.8
12.7	11.5	37.0	5.3	0.5
12.7	9.0	32.7	0.7	0.06
12.7	5.5	33.2	-7.8	0.2
12.7	3.0	32.7	-8.6	0.2
12.7	3.0	32.7	-8.6	0.2
12.7	0.5	33.2	-7.6	-0.3
12.7	0.3	26.2	-5.1	0.3
9.7	11.5	36.0	1.8	5.0
9.7	9.0	34.5	-1.0	7.2
9.7	5.5	33.5	-6.3	5.8
9.7	3.0	30.0	-6.7	2.9
9.7	0.5	20.2	-1.0	0.7
9.7	0.3	20.2	-3.1	0.6
7.7	11.5	34.5	0.3	4.8
7.7	9.0	34.2	-1.2	7.5
7.7	5.5	30.0	-3.6	5.4
7.7	3.0	24.7	-5.6	3.7
7.7	0.5	21.5	-1.0	0.9
7.7	0.3	26.5	0.9	0.5

At flow depth H =13.5 cm

X	Y	Vx	Vy	Vz
6.8	13.0	31.0	9.0	4.6
6.8	9.0	26.0	9.0	4.6
6.8	7.0	17.5	-8.5	-0.8
7.0	13.0	33.0	-0.8	2.5
7.0	9.0	20.8	-0.8	2.5
7.0	7.0	21.7	-5.8	-0.4
7.7	9.0	20.2	-4.7	-8.9
7.7	3.0	17.3	-2.2	-2.7
7.7	0.5	13.8	-2.9	-1.7
7.7	0.3	13.8	-2.9	-1.7
9.7	9.0	23.0	-1.1	-2.5
9.7	5.5	20.5	-2.1	-5.6
9.7	3.0	19.2	-1.3	-2.9
9.7	0.5	18.2	-2.7	-1.9
9.7	0.3	19.1	-2.2	-1.5
12.7	9.0	23.0	-1.2	-7.7
12.7	5.5	23.2	-1.4	-6.5
12.7	3.0	24.9	0.6	-3.0
12.7	0.5	23.5	-2.1	-1.7
12.7	0.3	21.9	-1.3	-1.0
15.7	9.0	23.1	-0.6	-6.2
15.7	5.5	23.9	-0.5	-4.3
15.7	3.0	25.3	1.8	-1.3
15.7	0.5	24.3	-3.1	-1.0
15.7	0.3	24.2	-1.1	-1.3
17.7	9.0	21.2	-0.6	-3.5
17.7	5.5	24.1	0.0	-3.2
17.7	3.0	22.9	2.7	-1.4
17.7	0.5	24.8	-2.4	-0.8
17.7	0.3	24.9	-3.9	-1.2
18.6	13.0	44.0	8.5	0.4
18.6	9.0	36.4	8.5	0.4
18.6	7.0	22.2	3.8	1.3
18.4	13.0	45.0	5.4	1.0
18.4	9.0	19.7	6.2	1.8
18.4	7.0	19.3	5.4	1.0

4.1.2 STRAIGHT COMPOUND CHANNELS.

At flow depth H=20 cm

x	y	Vx	Vy	Vz
15.1	12.5	62	1.7	-0.29
15.1	10.0	55.4	6.8	0.35
15.1	7.0	52.5	0.11	0.10
15.2	12.5	64.4	1.41	-0.02
15.2	10.0	51.4	8.32	1.30
15.2	7.0	71.0	1.73	0.58
18.0	16.5	48.6	-8.60	2.40
18.0	12.5	61.6	0.40	0.07
18.0	10.0	68.0	-0.20	0.03
18.0	7.0	69.0	0.28	0.13
18.0	5.0	70.5	0.69	0.47
18.0	3.0	68.8	0.68	0.58
18.0	1.0	62.3	0.18	0.58
18.0	0.5	56.3	0.21	0.63
18.0	0.3	55.6	-3.38	0.36
21.0	16.5	26.4	0.65	0.54
21.0	12.5	31.6	0.53	0.70
21.0	10.0	69.0	0.92	0.56
21.0	7.0	72.8	0.99	0.83
21.0	5.0	70.6	0.41	0.51
21.0	3.0	65.1	0.37	0.4
21.0	1.0	57.4	0.08	0.64
21.0	0.3	54.1	0.40	0.07
24.0	16.5	48.6	-0.20	0.03
24.0	12.5	61.6	0.28	0.13
24.0	10.0	72.0	0.69	0.47
24.0	7.0	71.9	0.68	0.58
24.0	5.0	70.6	0.18	0.58
24.0	3.0	66.0	0.21	0.63
24.0	1.0	62.7	1.41	-0.02
24.0	0.5	56.4	8.32	1.30
24.0	0.32	55.6	1.73	0.58
26.8	12.5	60.0	1.70	-0.29
26.8	10	51.8	6.80	0.35
26.8	7	71.6	0.11	0.1

At flow depth H=18 cm

x	y	Vx	Vy	Vz
15.1	13.4	50.16	-0.28	1.2
15.1	10.0	53.02	0.18	0.86
15.1	7.0	41.36	6.30	1.90
15.2	13.4	46.86	0.23	1.82
15.2	10.0	31.90	1.86	1.31
15.2	7.0	36.08	4.60	1.30
18.0	13.4	45.10	-5.30	1.50
18.0	10.0	53.68	0.23	0.61
18.0	7.0	55.35	-0.02	0.74
18.0	3.0	51.26	0.36	0.23
18.0	1.0	47.30	-0.26	0.17
18.0	0.5	40.70	-0.22	0.34
18.0	0.3	38.50	-0.40	0.40
21.0	13.4	52.58	0.10	0.10
21.0	10.0	53.24	0.76	-0.04
21.0	7.0	53.90	0.43	0.20
21.0	3.0	47.08	0.13	0.78
21.0	1.0	40.04	0.07	0.46
21.0	0.5	41.36	-0.18	0.18
21.0	0.3	37.40	0.32	0.48
24.0	13.4	45.10	-5.300	1.50
24.0	10.0	53.68	0.23	0.61
24.0	7.0	55.35	-0.02	0.74
24.0	3.0	51.26	0.36	0.23
24.0	1.0	47.30	-0.26	0.17
24.0	0.5	40.70	-0.22	0.34
24.0	0.3	38.50	-0.40	0.40
26.8	13.4	46.86	0.23	1.82
26.8	10.0	31.90	1.86	1.31
26.8	7.0	36.08	4.60	1.30
26.9	13.4	50.16	-0.28	1.20
26.9	10.0	53.02	0.18	0.86
26.9	7.0	41.36	6.30	1.90

At flow depth H=17 cm

x	y	Vx	Vy	Vz
15.1	12.5	57.51	1.70	-0.29
15.1	10.0	45.86	6.80	0.35
15.1	7.0	43.50	0.11	0.10
15.2	12.5	53.72	1.41	-0.02
15.2	10.0	42.57	8.32	1.30
15.2	7.0	58.79	1.73	0.58
18.0	16.5	40.22	-8.60	2.40
18.0	12.5	51.01	0.40	0.07
18.0	10.0	61.69	-0.20	0.03
18.0	7.0	59.51	0.28	0.13
18.0	5.0	58.38	0.69	0.47
18.0	3.0	56.96	0.68	0.58
18.0	1.0	51.59	0.18	0.58
18.0	0.50	46.63	0.21	0.63
18.0	0.32	46.05	-3.38	0.36
21.0	16.5	21.84	0.65	0.54
21.0	12.5	26.19	0.53	0.70
21.0	10.0	57.15	0.92	0.56
21.0	7.0	60.24	0.99	0.83
21.0	5.0	58.42	0.41	0.51
21.0	3.0	53.87	0.37	0.40
21.0	1.0	47.50	0.08	0.64
21.0	0.5	44.59	-8.60	2.40
21.0	0.32	44.77	0.40	0.07
24.0	16.5	40.22	-0.20	0.03
24.0	12.5	51.01	0.28	0.13
24.0	10.0	61.69	0.69	0.47
24.0	7.0	59.51	0.68	0.58
24.0	5.0	58.38	0.18	0.58
24.0	3.0	56.96	0.21	0.63
24.0	1.0	51.59	1.41	-0.02
24.0	0.50	46.62	8.32	1.30
24.0	0.32	46.05	1.73	0.58
26.8	12.5	53.72	1.70	-0.29
26.8	10.0	42.57	6.80	0.35
26.8	7.0	58.79	0.11	0.10

At flow depth H =15.5 cm

x	y	Vx	Vy	Vz
15.1	10.34	43.69	-7.50	1.75
15.1	9.00	54.62	0.71	-0.50
15.1	8.00	51.48	3.98	0.08
15.1	7.00	44.71	8.81	0.95
15.2	10.34	46.85	2.50	1.42
15.2	9.00	44.46	6.80	0.91
15.2	8.00	40.11	10.03	1.30
15.2	7.00	35.77	8.81	1.04
18.0	14.50	42.50	-8.90	2.30
18.0	10.34	49.13	0.27	0.25
18.0	7.00	59.31	-0.06	0.68
18.0	4.00	51.75	-0.21	0.58
18.0	1.00	48.42	0.06	0.74
18.0	0.50	43.72	-0.67	0.65
18.0	0.32	41.09	0.39	1.30
21.0	14.50	54.40	0.12	1.17
21.0	10.34	58.34	0.43	0.74
21.0	7.00	59.23	0.02	0.59
21.0	4.00	57.29	-0.11	0.513
21.0	1.00	49.18	-0.56	0.52
21.0	0.50	44.99	-8.90	2.30
21.0	0.32	44.61	0.27	0.25
24.0	14.50	42.50	-0.06	0.68
24.0	10.34	49.13	-0.21	0.58
24.0	7.00	59.31	0.06	0.74
24.0	4.00	51.75	-0.67	0.65
24.0	1.00	48.42	2.50	1.42
24.0	0.50	43.72	6.80	0.91
24.0	0.32	41.09	10.03	1.30
26.8	10.34	46.85	8.81	1.04
26.8	9.00	44.46	-7.50	1.75
26.8	8.00	40.17	0.71	-0.50
26.8	7.00	35.77	3.98	0.08
26.9	10.34	43.69	8.81	0.95

At flow depth H=14 cm

x	y	Vx	Vy	Vz
15.1	9.4	36.53	1.30	0.66
15.1	8.0	34.90	0.84	-0.05
15.1	7.0	34.15	6.40	0.23
15.2	9.4	33.29	1.73	0.34
15.2	8.0	30.90	8.08	0.22
15.2	7.0	29.30	6.67	0.42
18.0	14	45.00	1.41	1.56
18.0	9.4	38.19	0.54	0.75
18.0	7.0	37.50	0.70	0.46
18.0	4.0	34.56	0.56	0.43
18.0	2.0	31.30	-0.19	0.50
18.0	0.5	28.03	-0.23	0.73
18.0	0.32	25.37	1.29	1.81
21.0	14.0	38.00	0.96	1.28
21.0	9.4	38.29	0.65	1.10
21.0	7.0	37.60	0.35	0.72
21.0	4.0	34.80	-0.14	0.65
21.0	2.0	31.36	-0.60	0.60
21.0	0.5	28.16	1.41	1.56
21.0	0.3	25.18	0.54	0.75
24.0	14	37.50	0.70	0.46
24.0	9.4	38.19	0.56	0.43
24.0	7.0	37.50	-0.19	0.50
24.0	4.0	34.56	-0.23	0.73
24.0	2.0	31.30	1.73	0.34
24.0	0.5	28.03	8.08	0.22
24.0	0.32	25.37	6.67	0.42
26.8	9.4	33.29	1.30	0.66
26.8	8.0	30.90	0.84	-0.05
26.8	7.0	29.30	6.40	0.23

4.2 Contours

4.2.1 3D Field

Using very popular software called **3DField** all the velocity contours are plotted in it. It is very user-friendly and has a wide application in engineering areas.

3DField reads:
- scattered data points (X, Y, Z) and matrix data sets.
3DField creates maps, color and BW contours, color cells, color points, Direchlet tessellations, Delauney triangles, color and monotone relief, slices and circle values.

Features of this software are:

- 5 gridding methods.
- Automatic or user-defined contour intervals and ranges.
- Control over contour label format, font, frequency and spacing.
- Automatic or user-defined color for contour lines.
- Color fill between contours, either user-specified or as an automatic spectrum of your choice.
- Base map
- Regression 2D data.
- View and zoom BMP, GIF, PNG and JPG images
- Automatically and manually digitize image
- Import and export lines.
- OpenGL view with full screen rotating.
- Convert a simple contour bitmap to a 3D view
- Output maps as EMF, WMF, BMP, JPG, PNG file formats
- Insert maps (as EMF or bitmap) in any document Microsoft Office
- Multipage scale print
- Multilingual interface

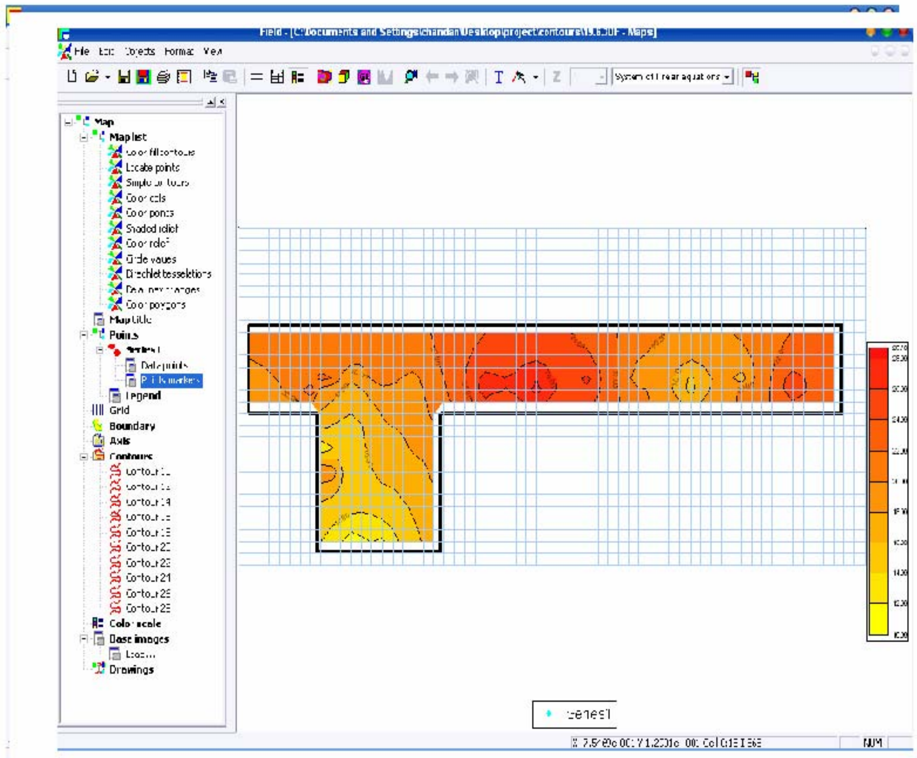
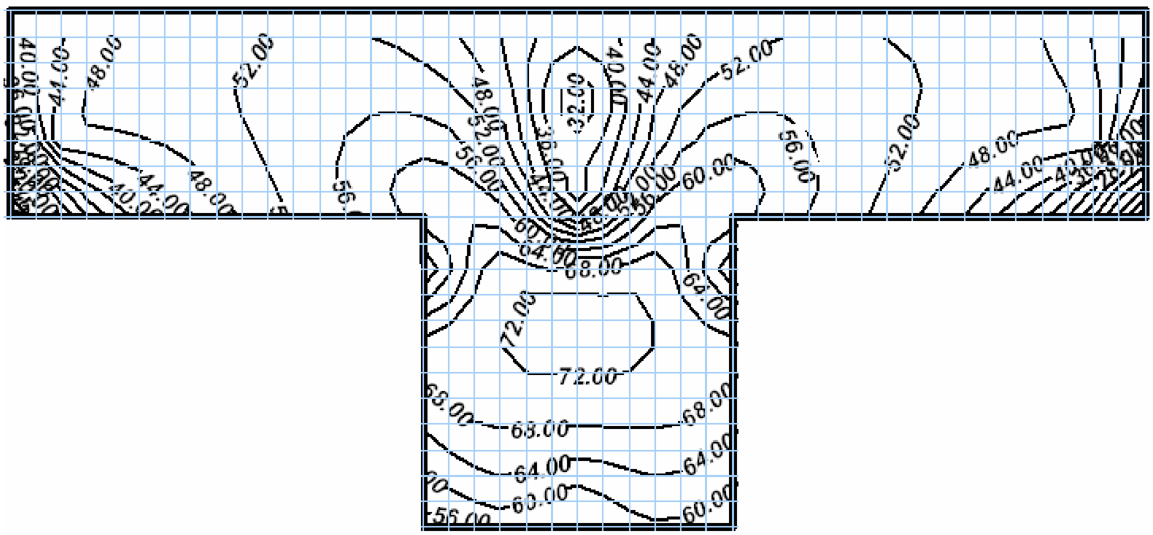


Fig 4.1 A 3DField software layout.

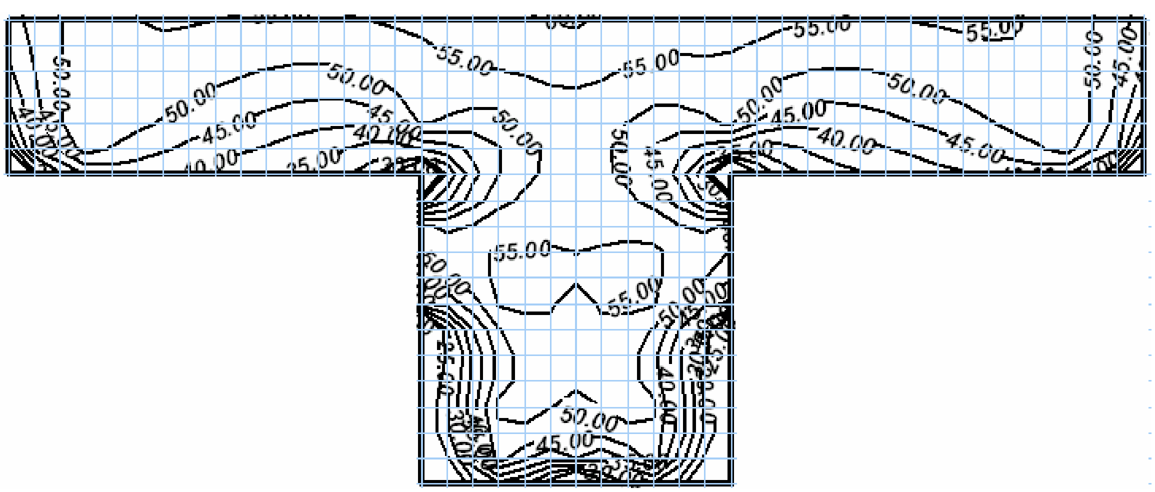
4.2.2 Straight compound channel

At flow depth H=20 cm



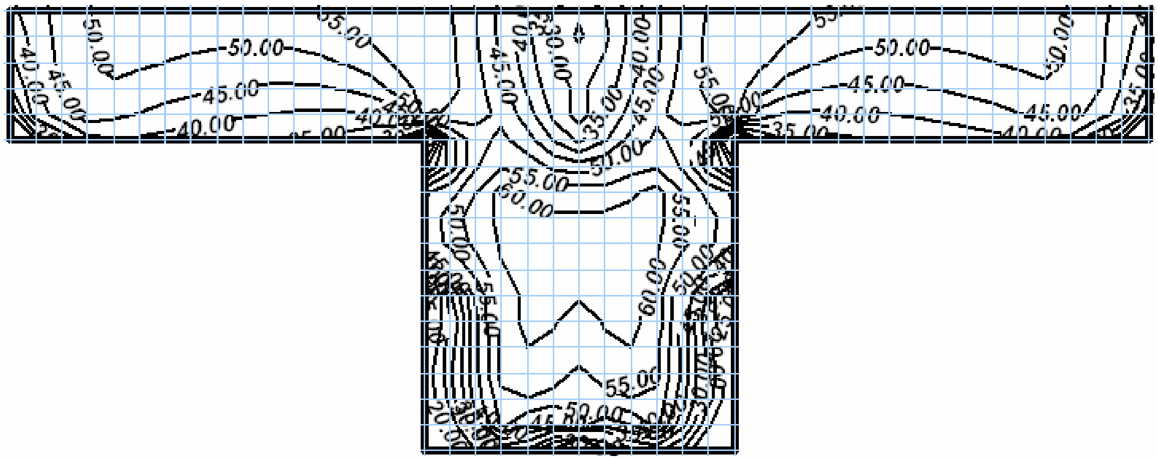
(A)

At flow depth H=18 cm



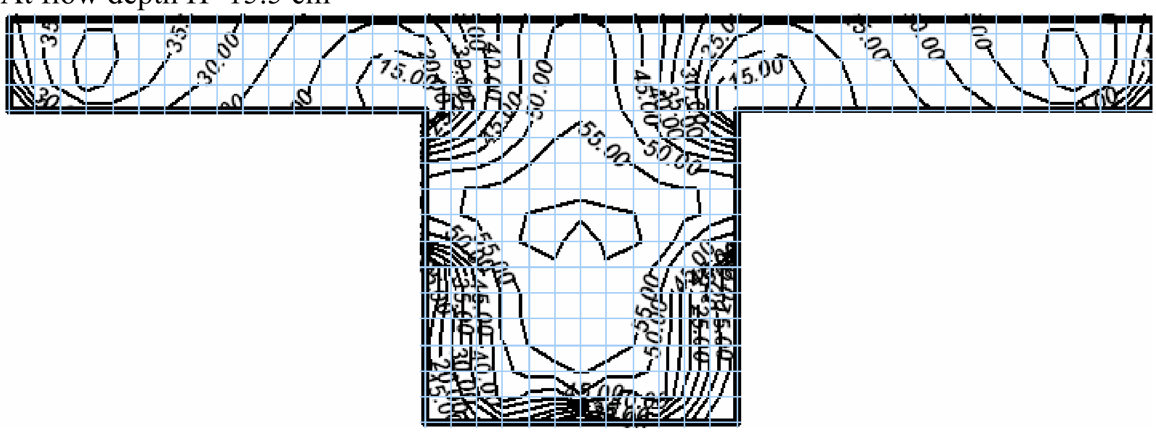
(B)

At flow depth H=17.0 cm



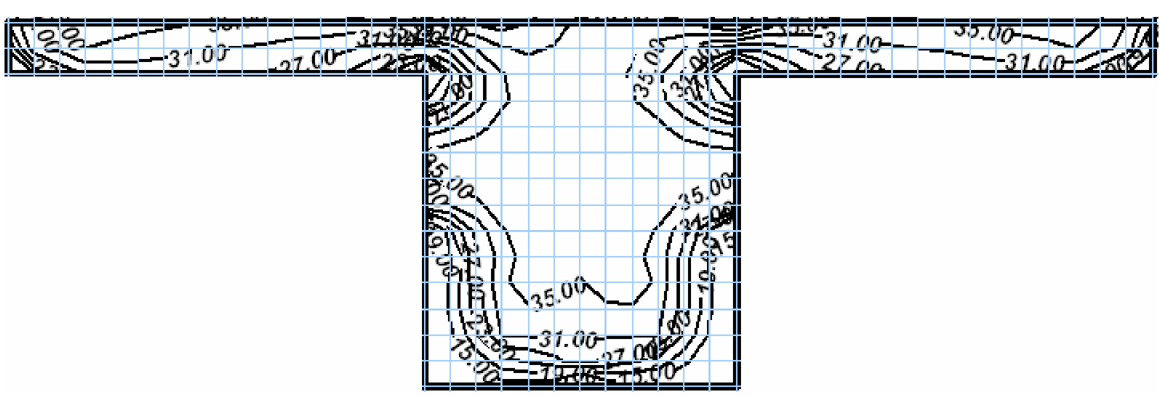
(C)

At flow depth H=15.5 cm



(D)

At flow depth H=14 cm

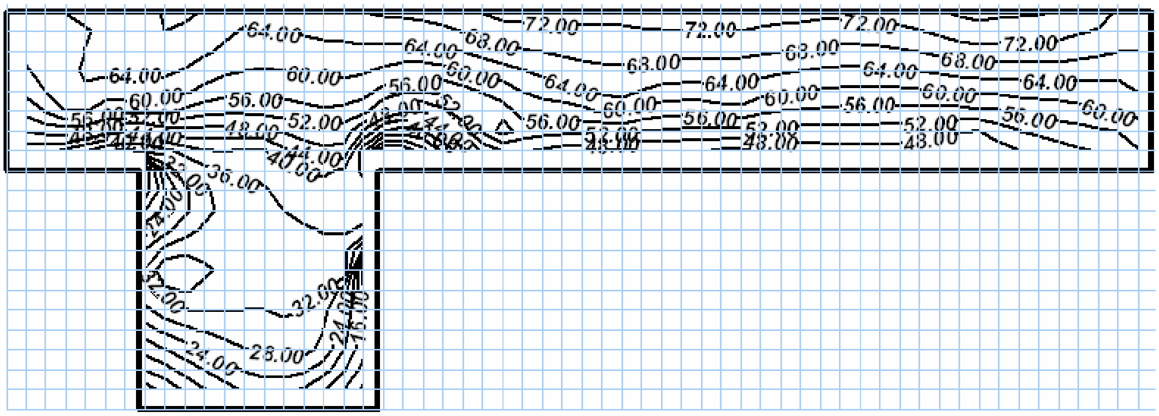


(E)

FIG 4.2 cross sections of straight compound channel with velocity contours(A,B,C,D,E) for various heights of flow.

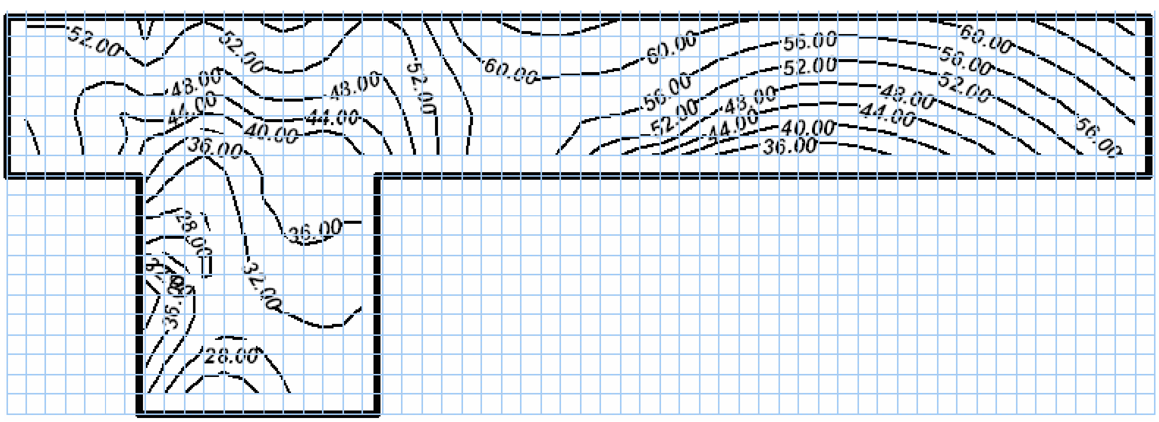
4.2.2 Meandering compound channel

At flow depth H=20.5 cm



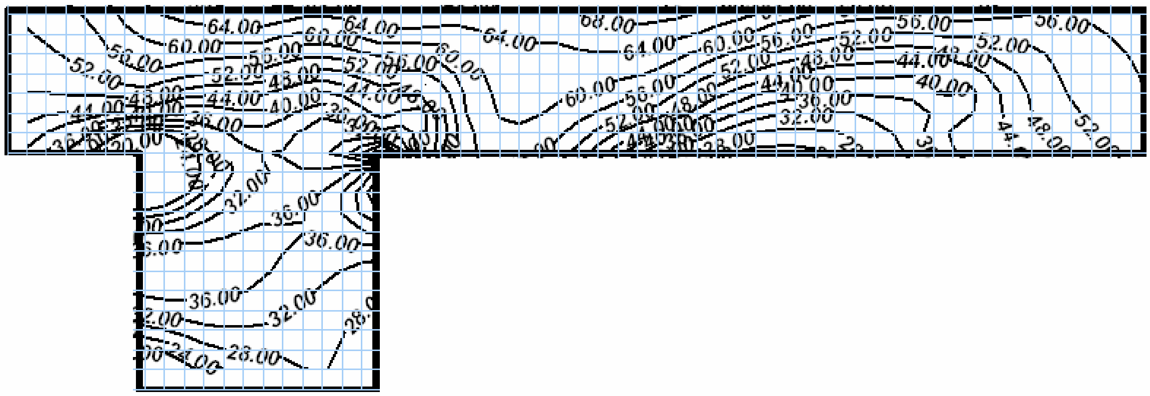
(F)

At flow depth H=19.5 cm



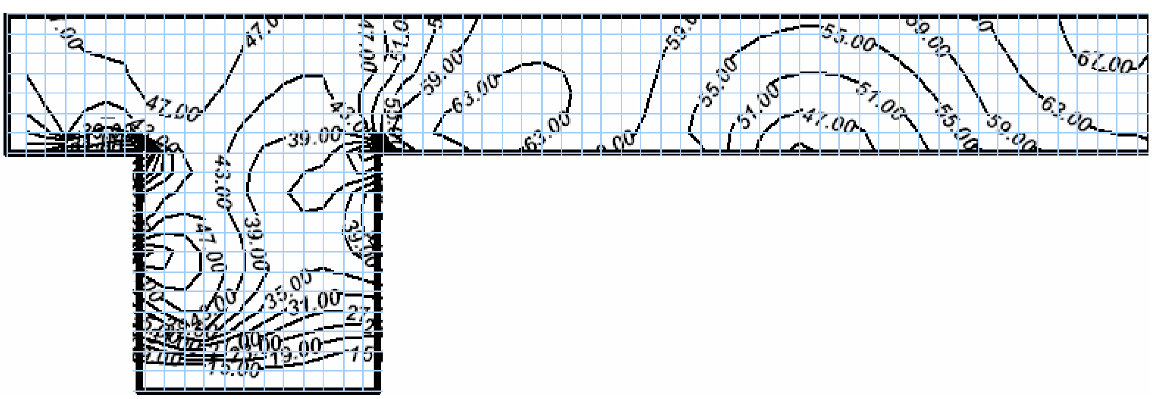
(G)

At flow depth H=19.02 cm



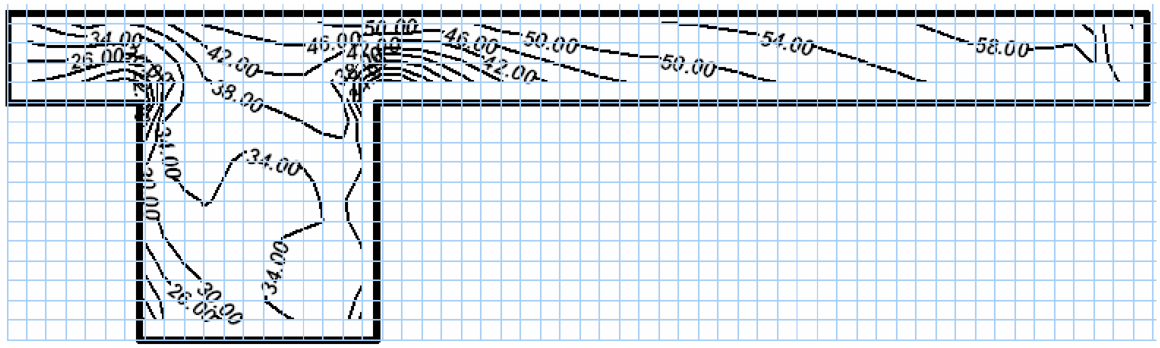
(H)

At flow depth H=18.96 cm



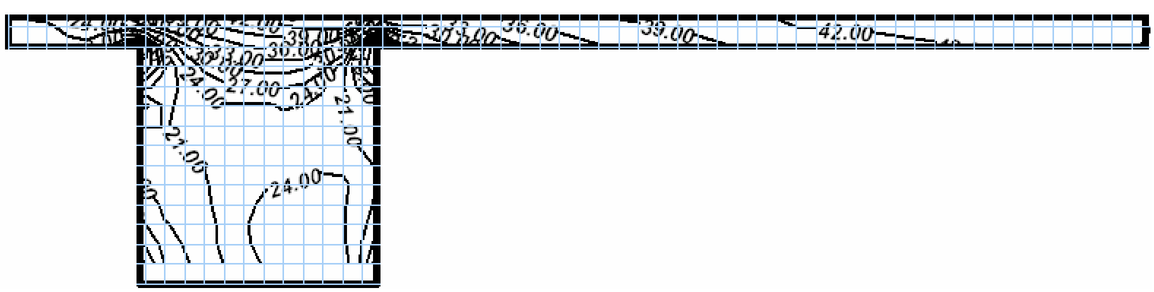
(I)

At flow depth H=16.5 cm



(J)

At flow depth H=13.5 cm



(K)

Fig 4.3 Velocity contours for meandering channels (F, G, H, I, J, K)

Chapter 5

ANALYSIS OF THE EXISTING DATA

5.1 Development of model

Plots of the isovels for the longitudinal velocities for the channel are used to find out the area-velocity distributions that are subsequently integrated to obtain the discharge of the main channel and floodplains separated by various assumed interface planes. At low depths of flow over floodplain, there is wide disparity between main channel and floodplain velocities confirming the process of momentum transfer between the main channel and floodplain. As the depth of flow over the floodplain increases, the velocities at the inner side of the floodplain are more rapid than the outer side, but the mean velocities in the floodplain and main channel becomes equal, indicating a marked reduction in momentum transfer.

the model $\%Q_{mc}$ proposed by knight and Demetriou (1984) for straight channel is given as

$$\%Q_{mc} = \frac{100}{[(\alpha-1)(\beta-1)]} + 108\left(\frac{\alpha-1}{\alpha}\right)^{\frac{1}{4}}(3.3\beta)^{\frac{4}{\alpha}}e^{-9.9\beta}$$

In order to account for meandering effects to the meandering compound channels, Patra and Kar (2000) proposed an improvement to the equation given by Knight and Demetriou (1984).and for meandering compound channel the equation obtained were,

$$\%Q_{mc} = \frac{100}{[(\alpha-1)\beta+1]} + F(\alpha,\beta)[1+36\beta Ln(S_r)/\delta]$$

$$\%Q_{mc} = \frac{100}{(\alpha-1)(\beta-1)} + 108\left(\frac{\alpha-1}{\alpha}\right)^{\frac{1}{4}}(3.3\beta)^{\frac{4}{\alpha}}e^{-9.9\beta}\left[1+36\beta Ln\, {S_r}/{\delta}\right]$$

Where S_r is the parameter representing the sinuosity of the meander channel (str. Valley length/ length along channel center). The std. error of estimate between the observed and computed percentages of discharge is 5.39 with correlation coefficient of 0.967.

For lower main channel separated from the compound section by a horizontal interface plain at the level of floodplain the following equations for the percentage of discharges and the section mean velocity in lower main channel have been obtained by best fit as

$$\%Q_{lmc} = \frac{100(1-\beta)}{[(\alpha-1)\beta+1]} + 300\left(\frac{\alpha-1}{\alpha}\right)^{1.25}(5.3\beta)^2 e^{-15.9\beta}$$

$$\%Q_{lmc} = \frac{100(1-\beta)}{[(\alpha-1)\beta+1]} + 300\left(\frac{\alpha-1}{\alpha}\right)^{1.25}(5.3\beta)^2 e^{-15.9\beta}\left[1+36\beta Ln(S_r)/\delta\right]$$

In which $\%Q_{lmc}$ is the percentage of flow in the lower main channel. For straight channels (i.e for $S_r = 1$) the equation attains the form of the equation proposed by Knight and Demetriuo(1984).

Our intension here is to identify an accurate, simple and yet a practicable applicable rational formula that holds the key to unwinding a powerful method of determining the discharge for the main channel and the flood plain. The equation should be equally capable to predict the upper main channel and lower main channel discharges with an accuracy greater than any of the earlier proposed methods.

From the present experimental investigation of both straight and meandering compound channel it has been found that $\%Q_{lmc}$ and $\%A_{lmc}$ follows a linear equation which can be expressed as

$$\frac{100Q_{mc}}{Q} = 100\left[\frac{A_{mc}}{A}\right] + \text{Constant (difference factor)}$$

This constant varies from flow depth to depth and is function of the geometrical parameters α and β, for straight compound channel which can be written as

$F(\alpha,\beta) = \dfrac{100Q_{mc}}{Q} - 100\left[\dfrac{A_{mc}}{A}\right]$, the values of Q_{mc} and A_{mc} being estimated experimentally from the experimental setup discussed above. The values of (DF) difference factor were then plotted against α and β, of the channel cross section. The variation of difference factor was then captured in equations. The variation was first observed by keeping α constant and varying β. The best fitted equation from the plot has been obtained

Difference factor=A $(\beta)^B$

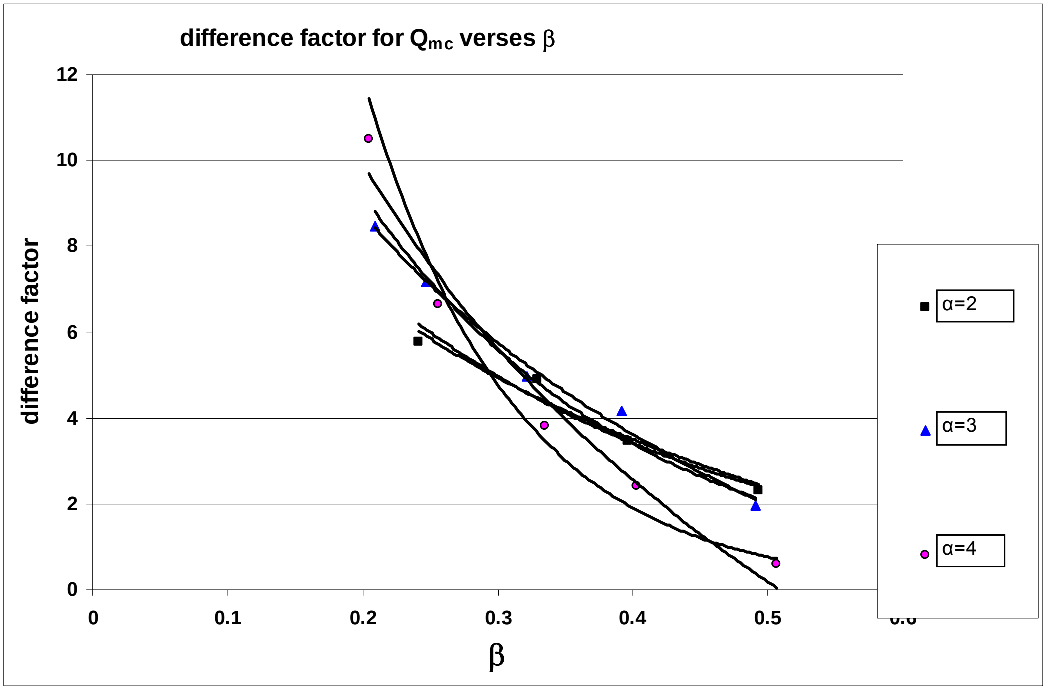


Fig 5.1 difference factor being plotted for α constant and varying β.

DF=-8.236Ln(x)-4.374------------ (A) the regression coefficient being 0.9085.

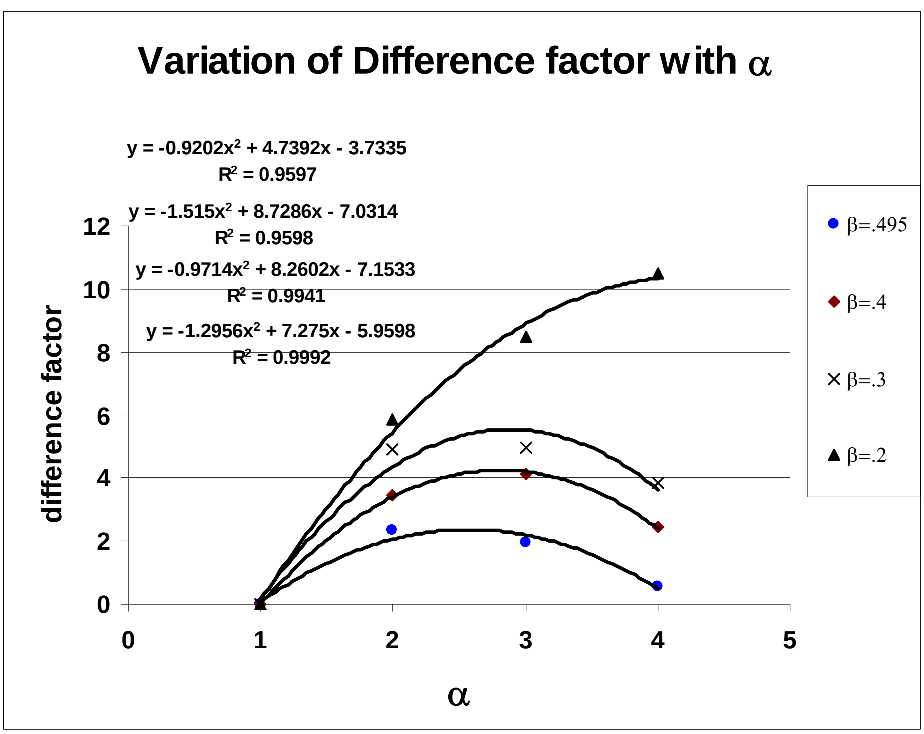


Fig 5.3 The difference factor was plotted Keeping the value of 'β'constant, and α varying

Thus, the equation DF=1.2956α² +7.275α-5.9598 ----------- (B) was considered to be the best fit curve which gave R^2 as 0.9992.

The final equation for

DF= A[(β)^B (B+C Log α)],for

Thus the final equation for

$$100\frac{Q_{mc}}{Q}=\frac{100}{[(\alpha-1)(\beta-1)]}+\left[\{(4.325\beta-1.5097)*Ln(1.22\alpha)\}*\{0.27*(-8.26Ln\beta-4.374)*(-1.2956\alpha^2+7.275\alpha-5.95)\}\right]$$

this equation is for straight compound channel. For meandering compound channel the meandering effect has been incorporated and a final general form has been obtained and given as

$$100\frac{Q_{mc}}{Q}=\frac{100}{[(\alpha-1)(\beta-1)]}+\left[\{(4.325\beta-1.5097)Ln(1.22\alpha)\}\{0.27(-8.26Ln\beta-4.374)(-1.2956\alpha^2+7.275\alpha-5.95)(1+(4.325\beta-1.5097)Ln(S_r\alpha))\}\right]$$

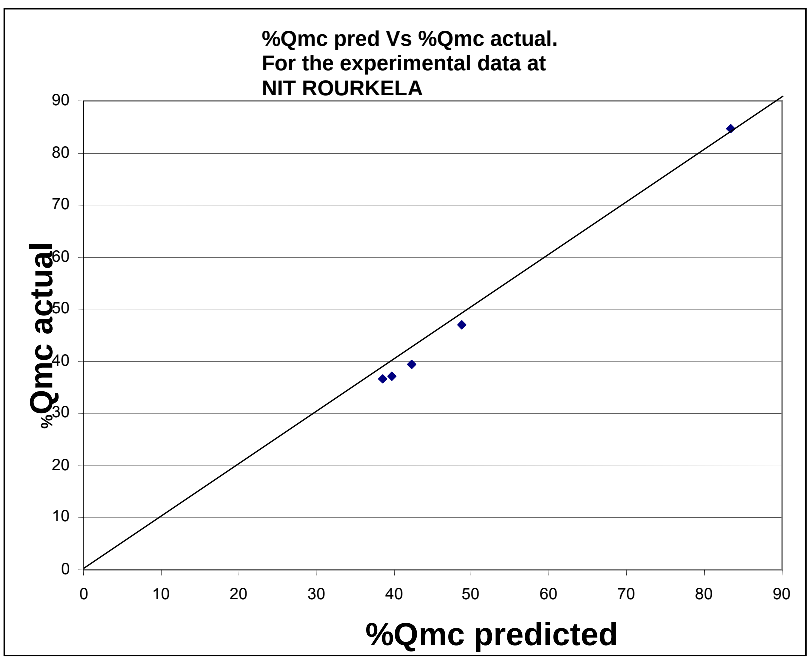


Fig 5.4 % Q_{mc} predicted by the model developed against the % Q_{mc} actually for meandering channels

The above graph is a plot for % Q_{mc} predicted by the model developed against the % Q_{mc} actually calculated by counting the number of squares in the fig(4.3F,G,H,I,J,K). The above data is for meandering channels. The plot for straight channels is given below and the % Q_{mc} actual is calculated by counting the number of squares in the fig(4.2,A,B,C,D,E,F).

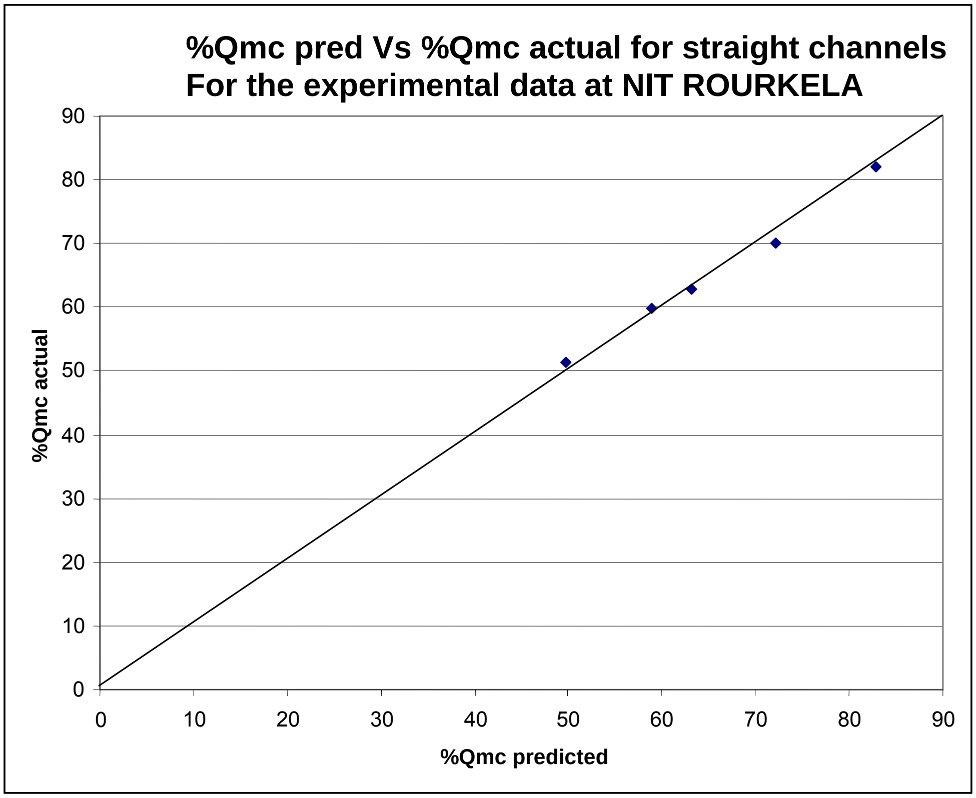


Fig 5.5 % Q_{mc} predicted by the model developed against the % Q_{mc} actually for straight channels.

5.2Validation of the data

The results obtained from the equation in this model were validated with other previously conducted experimental data and the plots for Q_{mc} actually observed at the time of experimentation and Q_{mc} predicted through the equation developed in this model were plotted.

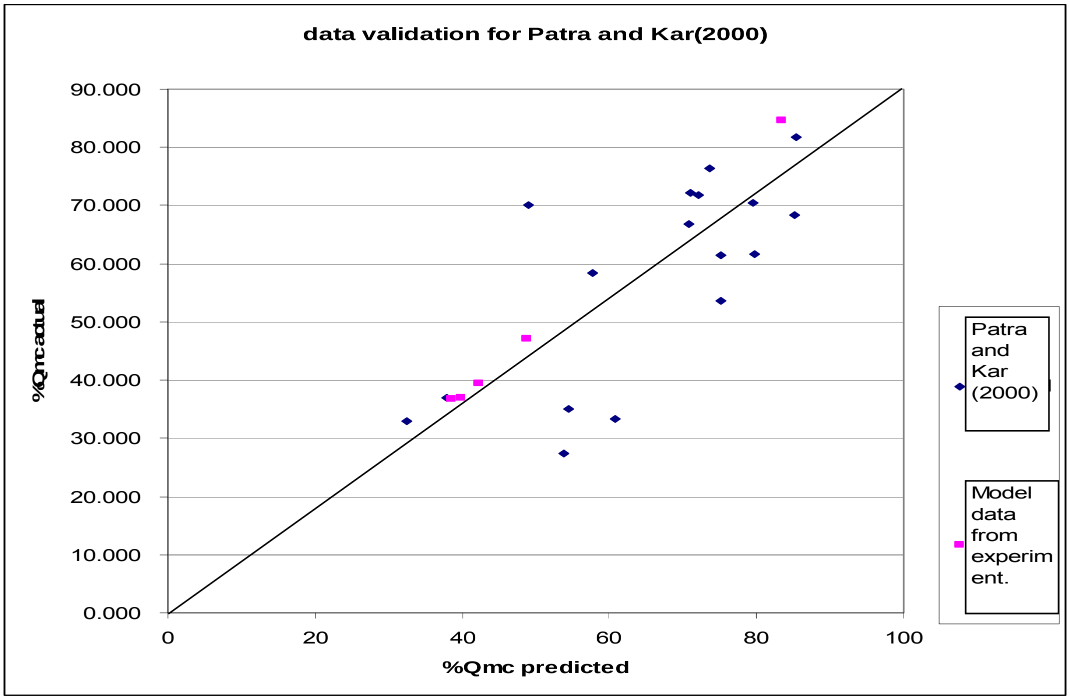


Fig 5.6 % Q_{mc} predicted by the model developed against the % Q_{mc} actually for data by Patra and Kar(2000) and the data predicted by the proposed model.

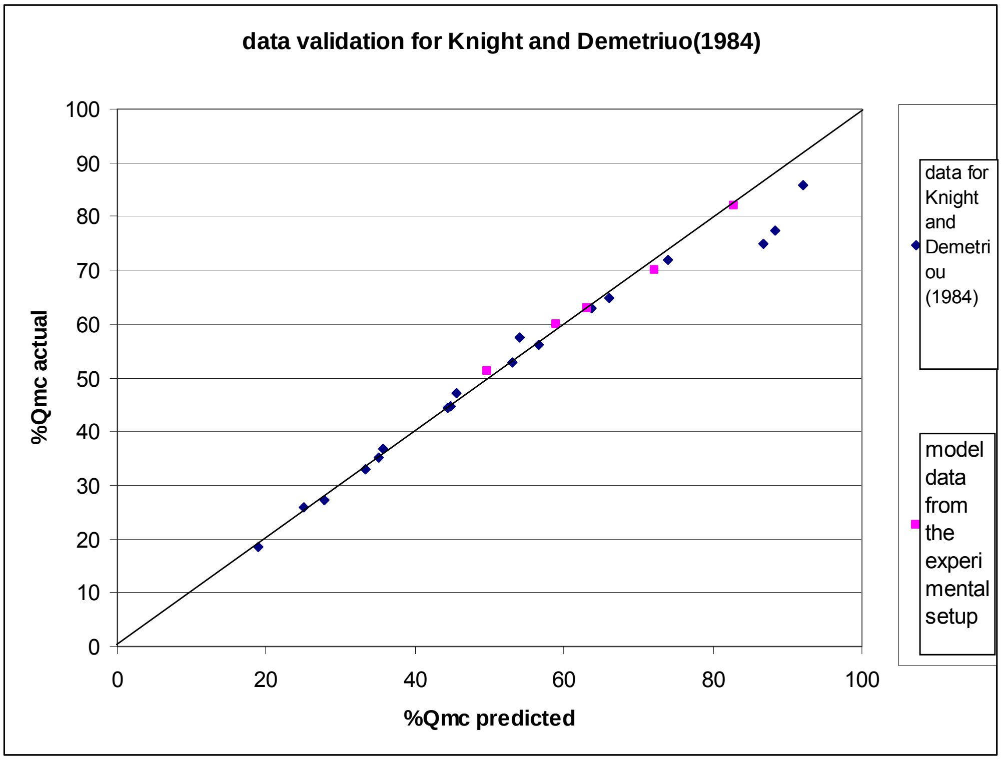


Fig 5.7 % Q_{mc} predicted by the model developed against the % Q_{mc} actually for data by Knight and Demetriou(1984) and the data predicted by the proposed model.

Conclusion

- The distribution of flow discharge along the perimeter of straight and meandering compound channels are examined and a rational relationship to predict the percentage discharge is obtained.
- The % Q_{mc} so found out happened to be in greater accuracy as compared with the Patra,K.C.,Kar,S.K.,(2000) data and Knight and Demetriou(1983) data.
- The results obtained from the equation in this paper were validated with other previously conducted experimental data and the plots for Q_{mc} actually observed at the time of experimentation and Q_{mc} obtained through the equation developed in this paper.
- The equation being dimensionless, it is more practically realizable. The equation developed is not empirical. It is purely rational and known to satisfy the river plain components discharges well.
- The discharge values predicted are more accurate. The equation involves only the geometrical parameters of any natural channel.
- The equations presented in the paper are considered to be a reasonable attempt on defining the interaction between main channel and flood plain flow. They will be of particular benefit to those engaged in the numerical modeling of hydraulic flows.
- For the meandering compound channels the important parameters effecting the flow distribution are sinuosity(S_r) ,the amplitude (ε) ,relative depth (β) and the width ratio (α) and the aspect ratio(δ). These five dimensionless parameters are used to form general equations representing the total flow contribution in main channels. The proposed equations give good result with the observed data.
- It is suggested that further investigation be focused on extending the present analysis to the compound channel of different cross sections such as trapezoidal cross sections.

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Photo Gallery:

Plate 1: Front View of ADV

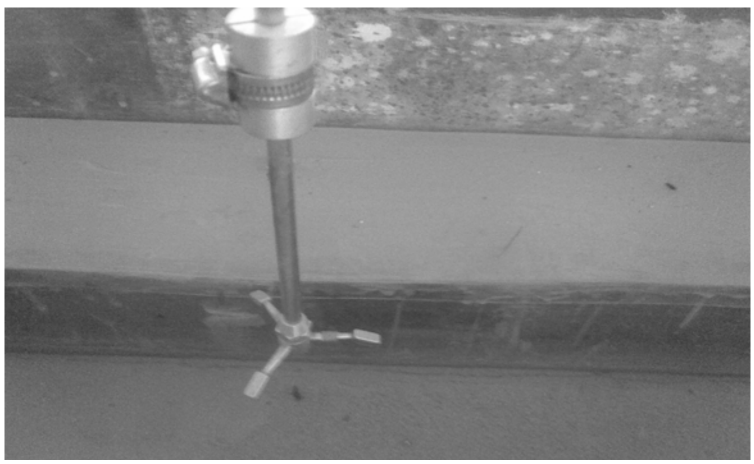

Plate 2: Blades of ADV

Plate 3: Measuring the velocities

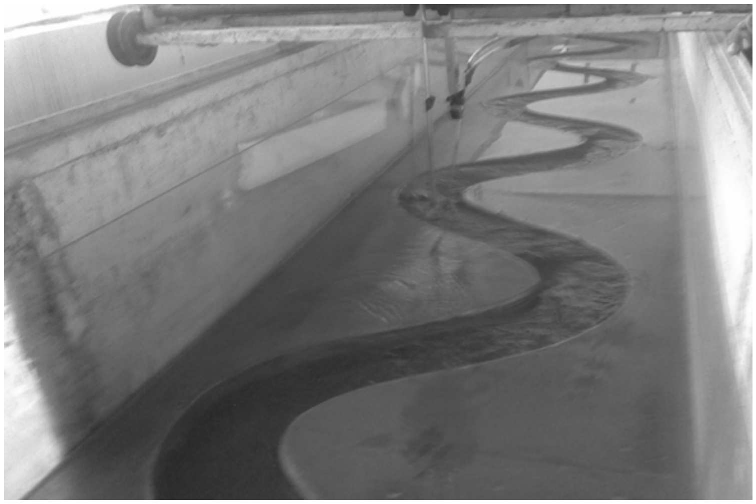

Plate 4: A close look at the channels

Plate 5: Adjusting the delicate ADV